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Comprehensive utilizations of biogas in Inner Mongolia, China

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ABSTRACT

With the increasing number of large scale and centralized livestock farms in Inner Mongolia Autonomous Region (IMAR), there is an urgent need to dispose huge amount of animal excrement. In combining with economic restructuring in agricultural and pastoral areas in IMAR, it is an important means to facilitate the development of circular economy and to increase the incomes of farmers by fully utilizing biogas as the link to actively promote the integrated eco-agricultural industry in IMAR. In accordance with the development of circular economy, comprehensive utilizations of biogas is an effective mode to make use of agricultural organic wastes, which can significantly improve the efficiency of resource consumption, extend the agricultural production chain, fulfill "win-win-win" situation between economic development, ecological improvement and structural optimization, and acquire larger economic, social and environmental benefits. Based upon the investigation of biomass resources in IMAR, China and the experience on bioenergy development from developed countries, the purpose of this study is to institute the theoretical foundation to formulate policy on bioenergy development, to support the progress of bioenergy technologies, to establish specific system of bioenergy industry, to gradually fulfill the large-scale development of bioenergy, and to provide clean, efficient and commercialized bioenergy to energy market. The study is mainly focusing on four main animal husbandry areas in IMAR, Chifeng, Erdos, Huhhot, and Xilinguole, namely, to survey the biogas utilizations on large-scale farms, to assess the potential of biogas power generation and comprehensive utilizations, to carry out the post-project analysis on established and representative biogas projects, and to propose a mode of biogas comprehensive utilizations in according with the characteristics of IMAR.

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1. Introduction

For the past two decades, rapid depletion of fossil fuel resources and gradual climate changes resulted from excessive greenhouse gases emissions have increasingly attracted people's attention, worldwide. In order to achieve sustainable development, comprehensive utilizations of renewable resources, efficient energy production and the reduction of energy consumption have become our major tasks [1]. Bioenergy (biomass energy), derived from plant or animal sources, is an alternative clean energy with great potential for energy conservation. Biogas, referred as the gas produced by microbial degradation of organic matter through anaerobic process, is an efficient method to convert biomass into energy for cooking, heating, fueling, power generation and various purposes [2–4]. In Europe, the United States and other developed countries, biogas technology, recognized as an effective way of dealing with excrement for waste resources recycling, plays a significant role in improving energy structure, environment and health, and reducing greenhouse gases emissions. Right now, the development of biogas technology in Europe is the most advanced and mature in the world, with extensive applications.

In China, the development of biogas industry was quite slow and backward before 1990s. After years of researches and experiments, there were great achievements on the improvement of biogas technology to provide the significant platform for the development and applications of biogas industry, especially for rural and agricultural areas [5–7]. Inner Mongolia Autonomous Region (hereinafter referred as "IMAR"), the third-largest province in China located in northern frontier with an area of 1.183 million km^2, is one of the major provinces included in *the Western Region Development Strategy* of the "10th Five-Year Plan" of China, where rural renewable energy construction, and ecological and environmental protection are stipulated as key projects. With vast natural grassland, IMAR has become an important base for livestock husbandry productions. Through further restructuring of agriculture and livestock husbandry, and continuous expanding of farming scale, there are a large number of scale farmers, farming communities and farming enterprises emerging to promote the rapid social and economic development in rural and pastoral areas. Focusing on four main livestock husbandry areas in IMAR, Chifeng, Erdos, Huhhot, and Xilinguole, namely, the objective of this research is to institute the fundamental basis to propose a suitable mode of biogas comprehensive utilizations on large and medium pasture farms in IMAR and to provide the reference of decision-making for IMAR Government to formulate development strategy on biogas comprehensive utilizations on large and medium pasture farms, through broad survey and analysis on the utilizations of established and representative large-scale biogas projects.

2. Methodology

According to specific tasks and anticipated outputs, the methodology of this research is designed to comprise of four major parts, domestic and foreign literature review, collective discussions, individual interview, and on-site survey, respectively. All tasks were completed by the end of 2009.

(a) Literature review: Literature and information on natural resources, socio-economic development, agricultural and industrial structure and policies, planning, statistics data and information on biogas development of IMAR were collected.
(b) Collective discussions: Collective discussions were held with personnel in charge of the farms and biogas projects to understand the background information, relevant policies and basic data.
(c) Individual interview: Individual interview were held with technical staffs to understand detailed technical information.
(d) On-site survey: The objects of field survey were selected via thorough consideration on the scale of farming enterprises,

Table 1
Summary of the questionnaire.

Category	Major content
1. Basic information	Name, address and ownership
2. Cultivation information	Species, scale and type
3. Feeding information	Grass, straw and fodder
4. Surrounding information	Crops, acreage, total and unit productions
5. Excrement information	Production, capacity, cleaning, storage and retention time
6. Excrement disposal	Biogas and fertilizer production and direct field application
7. Biogas utilization	Production rate, storage capacity and power generation
8. Public opinions	Acceptance and recommendations from local residents
9. Preparer information	Name, educational background and means of contact
10. Recommendations	Policy, regulations and economic incentives

feeding type, regional characteristics, and so on, such as (i) the Large Scale Biogas Power Generation and Comprehensive Utilizations Project, Mengniu Austasia Demonstration Pasture, (ii) the Medium Scale Biogas Project for Baita Breeding Pig Farm, (iii) the Biogas Project for the Erdos Demonstration Park of Modern Agriculture and Livestock Husbandry Technology, and (iv) other biogas projects on large and medium farms in Chifeng and Xilinguole. Before implementing on-site survey, a questionnaire was designed for staffs of large- and medium-scale pastures and biogas engineering to fill out. In order to collect all necessary information, the questionnaire, composed of 10 various categories, is trying to cover as many fields as possible, as summarized in Table 1.

3. Background analysis

3.1. Excrement resource allocation

As indicated in the "2008 Statistical Report on National Economics and Social Development of Inner Mongolia Autonomous Region (IMAR Report 2008)," [8] the total number of livestock was more than 100 million (including 10 million cattle/cow, 84 million sheep, and 10 million pigs), and the total number of poultry was about 40 million. Based upon the coefficients provided in "Handbook on Pollutants Production and Emission Coefficients from Livestock and Poultry Industry (the Handbook 2009)", [9] the excrement production was estimated around 150 million tons, mainly came from dairy farms located in pastoral, semi-agricultural and semi-pastoral, and agricultural areas. About 63.3% of excrement production came from cattle/cow, followed by sheep (30.5%), pig (5.5%) and poultry (0.7%). Due to other utilizations of sheep excrement and low quantity of poultry excrement, major focuses of this study were concentrating on resources reclamation and biogas production potential from cattle/cow and pig excrement.

Cattle/cow farms are mostly concentrated in Chifeng, Tongliao, Hulunbeier and Xilinguole. In 2008, the total number of on-hand cattle/cow for each city was 2.3853, 2.2658, 1.6015 and 1.0263 million, respectively, to jointly take up 69% of the total number of on-hand cattle/cow in IMAR, where the excrement production was 21.7659, 20.6754, 14.6137 and 9.365 million tons for each city, correspondingly. Pig farms are mainly concentrated in Tongliao and Chifeng. In 2008, the total number of on-hand pigs for Tongliao and Chifeng were 3.697 and 2.0028 million, respectively, accounting for 35.7% and 19.4% of the total number of on-hand pigs in IMAR, where excrement production were 2.969 and 1.608 million tons, as shown in Table 2.

3.2. Biogas production potential analysis

Regional analysis on biogas production potential is an important reference for the construction of large and medium biogas projects. As presented in Table 2, in 2008, total biogas production potential in IMAR was estimated 4.4548 billion m^3, where about 3.9430 billion m^3 was from cattle/cow excrement and 0.5118 billion m^3 was from pig excrement. Tongliao and Chifeng are cities with higher biogas production potential, 1035 and 996 million m^3, respectively, to sum up more than 45% of total biogas production potential of IMAR. Biogas production potentials of Hulunbeier and Xilinguole were 653 and 388 million m^3, accounting for 14.65% and 8.72%, correspondingly. Biogas production potentials for the rest of areas were relatively low.

3.3. Biogas production potential analysis for scale farms in four survey areas

Scale farming is an intensive and meticulous breeding pattern for farms with specific breeding capacity, through the application of advanced technology of production and certain facilities. Currently, there are no definite standards for breeding capacity, facilities and technology for scale farming, in China. According to the "Discharge Standard of Pollutants for Livestock and Poultry Breeding" (GB18596-2001), [10] the specific breeding capacity of each animal on-hand for intensive breeding pattern is defined as: 500-pig (more than 25 kg), or 100-cow, 200-cattle, or 15,000-layer, or 30,000-broiler. For farms with various animals, the scales of other animals shall all be converted into equivalent scales of pig farming, where the conversion ratios are 30:1 for layer, 60:1 for broiler, 1:10 for cow, and 1:5 for cattle. According to the "Measures for Pollution Prevention and Control of Livestock and Poultry Farm Management," [11] promulgated in 2001 by the State Environmental Protection Agency (SEPA, had been reorganized as the Ministry of Environmental Protection, MEP, in 2008), the specific breeding capacity of scale farming for each animal on-hand is defined as: 500-pig, or 100-cow, or 30,000-poultry, which was applied in this study.

As mentioned previously, the objects of on-site survey were selected through careful consideration on the scale of farming enterprises, feeding type and regional factors, and so on. Therefore, this study was then focusing on four major areas, Chifeng, Erdos, Huhhot and Xilinguole, namely.

3.3.1. Chifeng

Chifeng is famous for livestock and poultry cultivation, with several representative scale farming, such as "Inner Mongolia Prairie Xingfa Co., Ltd.," and "Inner Mongolia Saifeiya Co., Ltd." Due to unique geographical location adjacent to Heilongjiang, Jilin and Liaoning provinces, livestock and poultry trade is particularly active, since 2000. Right now, Chifeng and Tongliao region has become the largest livestock trading center in China. However, the proportions of scale farming for cattle/cow and pig are only 6.83% and 1.00%, respectively, which are quite low in comparing with other survey areas. According to the survey, total biogas production potential of scale farming in Chifeng was estimated 62.2 million m^3 to account for 6.25% of total biogas production potential. Power generation potential of scale farming was estimated 16.1 MW.

3.3.2. Erdos

Erdos takes the leading role for booming economic development of IMAR with fast development of livestock husbandry from traditional farming to modern cultivation. The trend of livestock husbandry development is from individual farming to professional farming, then to scale farming. Erdos is the area with great potential for scale farming in IMAR. Currently, the proportions of scale

Table 2
Excrement resources allocation and biogas production potential in IMAR.

Area		Alashan	Baotou	Bayannaoer	Chifeng	Erdos	Huhhot	Hulunbeier	Tongliao	Wuhai	Wulanchabu	Xilinguole	Xing'an	SUM
Cattle/Cow: total on-hand number (million capita)		0.093	0.493	0.325	2.385	0.330	0.742	1.602	2.266	0.003	0.618	1.026	0.607	10.488
Excrement	Emissions (million tons)	0.844	4.494	2.961	21.766	3.009	6.772	14.614	20.675	0.030	5.635	9.365	5.539	95.703
	Biogas production potential (100 million m^3/yr)	0.338	1.798	1.184	8.706	1.203	2.709	5.845	8.270	0.012	2.254	3.746	2.216	38.281
Urine	Emissions (million tons/yr)	0.844	4.494	2.961	21.766	3.009	6.772	14.614	20.675	0.030	5.635	9.365	5.539	95.703
	Biogas production potential (100 million m^3/yr)	0.010	0.054	0.036	0.261	0.036	0.081	0.175	0.248	0.000	0.068	0.112	0.066	1.148
Sum of biogas production potential (100 million m^3/yr)		0.348	1.852	1.220	8.968	1.240	2.790	6.021	8.518	0.012	2.321	3.858	2.282	39.430
Percentage		0.88%	4.70%	3.09%	22.74%	3.14%	7.08%	15.27%	21.60%	0.03%	5.89%	9.79%	5.79%	100.00%
Pig: total on-hand number (million capita)		0.007	0.395	0.600	2.003	0.646	0.389	1.020	3.697	0.055	0.725	0.049	0.765	10.350
Excremen	Emissions (million tons)	0.005	0.317	0.481	1.608	0.519	0.312	0.819	2.969	0.044	0.582	0.040	0.614	8.311
	Biogas production potential (100 million m^3/yr)	0.003	0.190	0.289	0.965	0.311	0.187	0.491	1.781	0.026	0.349	0.024	0.369	4.987
Urine	Emissions (million tons/yr)	0.007	0.418	0.635	2.120	0.684	0.412	1.080	3.913	0.058	0.767	0.052	0.810	10.956
	Biogas production potential (100 million m^3/yr)	0.000	0.005	0.008	0.025	0.008	0.005	0.013	0.047	0.001	0.009	0.001	0.010	0.131
Sum of biogas production potential (100 million m^3/yr)		0.003	0.195	0.296	0.990	0.320	0.192	0.504	1.828	0.027	0.359	0.024	0.378	5.118
Percentage		0.06%	3.82%	5.79%	19.35%	6.25%	3.76%	9.85%	35.72%	0.53%	7.00%	0.48%	7.39%	100.00%
Total biogas production potential (100 million m^3/yr)		0.351	2.047	1.516	9.958	1.559	2.982	6.525	10.346	0.040	2.680	3.883	2.660	44.548
Percentage		0.79%	4.59%	3.40%	22.35%	3.50%	6.69%	14.65%	23.23%	0.09%	6.02%	8.72%	5.97%	100.00%

farming for cattle/cow and pig are 34.12% and 15.47%, respectively. According to the survey, total biogas production potential of scale farming in Erdos was estimated 47.2 million m^3 to account for 30.30% of total biogas production potential. Power generation potential of scale farming was estimated 12.1 MW.

3.3.3. Huhhot

Huhhot is the earliest region to develop dairy industry, where the development scale is the largest, currently in China. Cow is the major livestock. Most farms are scale professional cow farms, such as Mengniu Austasia Demonstration Pasture and the Yili Tuzuoqi Demonstration Park of Modern Livestock Husbandry Technology. Presently, the proportions of scale farming for cow and pig are 32.88% and 1.80%, respectively. According to the survey, total biogas production potential of scale farming in Huhhot was estimated 92.1 million m^3 to account for 30.87% of total biogas production potential. Power generation potential of scale farming was estimated 23.7 MW.

3.3.4. Xilinguole

Xilinguole is a traditional pastoral area. In recent years, the scale of cultivation has been greatly increased. Right now, the proportions of scale farming for cow and pig are 33.73% and 38.62%, correspondingly. According to the survey, total biogas production potential of scale farming in Xilinguole was estimated 131.1 million m^3 to account for 33.76% of total biogas production potential. Power generation potential of scale farming was estimated 33.7 MW.

Biogas production and power generation potentials of scale farming in Chifeng, Erdos, Huhhot and Xilinguole are summarized in Table 3.

Table 3
Biogas production and power generation potentials of scale farming in survey areas.

Area	Chifeng	Erdos	Huhhot	Xilinguole	SUM
Cattle/Cow: total on-hand number (million capita)	2.385	0.330	0.742	1.026	4.483
Number of scale farms	10	10	52	31	103
Capita in scale farms (million)	0.163	0.113	0.244	0.346	0.866
Percentage of scale farming	6.83%	34.12%	32.88%	33.73%	19.30%
Biogas production potential of scale farming (100 million m^3/yr)	0.612	0.423	0.917	1.302	3.254
Pig: total on-hand number (million capita)	2.003	0.646	0.389	0.049	3.087
Number of scale farms	1	5	1	4	11
Capita in scale farms (million)	0.020	0.100	0.007	0.019	0.146
Percentage of scale farming	1.00%	15.47%	1.80%	38.62%	4.73%
Biogas production potential of scale farming (100 million m^3/yr)	0.010	0.049	0.003	0.009	0.072
Total biogas production potential (100 million m^3/yr)	9.958	1.559	2.982	3.883	18.382
Total biogas production potential of scale farming (100 million m^3/yr)	0.622	0.472	0.921	1.311	3.326
Percentage	6.25%	30.30%	30.87%	33.76%	18.09%
Power generation potential of scale farming (MW)	16.0	12.1	23.7	33.7	85.4

4. Current status of biogas projects in IMAR

4.1. The development of biogas projects

Based upon the statistics from the Ministry of Agriculture (MOA) [12], biogas projects for large and medium pasture farms in IMAR began to construct in 2003, and the first biogas project was put into operation with a 150 m^3 fermentation tank in 2004. Despite late start of biogas projects, the State has invested heavily in IMAR, in recent years. For example, the State granted ¥260 million funds on biogas projects in IMAR, in 2008. Lately, the development of biogas projects was rapid, where the scale for each project has been gradually increased. From 2005 to 2007, the number of new biogas projects for each year was 3, 1, and 3, respectively. By the end of 2007, there were 9 large and medium biogas projects in IMAR, where total capacity of biogas pool is 12,400 m^3, annual biogas production is 4.35 million m^3, and average daily biogas production is more than 1300 m^3 for each project. Among them, there were 8 large biogas projects, where total capacity of biogas pool is 12,300 m^3, annual biogas production is 4.34 million m^3, and average daily biogas production is 1500 m^3, as shown in Table 4. By the end of 2008, 14 large and medium biogas projects were completed, 6 biogas projects were still under construction and 36 new biogas projects were granted. Currently in IMAR, biogas comprehensive utilizations is less than 1% of full potential, and there is much room for development.

4.2. Technology of biogas projects

There are several fermentation techniques mainly including 'Up-Flow Solids Reactor (USR),' 'Continuous Stirred Tank Reactor (CSTR),' 'Plug Flow Reactor (PFR),' and, etc. [13,14]. Currently, among the established biogas projects in IMAR, USR and CSTR are mainly adopted fermentation techniques, since these techniques are more mature and have provided concrete technical support for the construction of large and medium biogas projects in IMAR. For biogas storage equipment, double-membrane dry storage tank is mostly adopted. Few biogas projects adopt low-pressure wet storage tank.

Due to special weather conditions in IMAR, it is very important to choose appropriate heating instruments, especially fermentation tanks, for biogas projects. Presently, the heating devices for biogas projects in IMAR are mainly solar thermal collector and biogas boilers. As for biogas cogeneration projects, waste heat from cogeneration is mostly used as heating for fermentation tanks. For projects with insufficient capacity of power generation, some alternate heating boilers (such as coal-burning steam boilers or biogas boilers) are needed for fermentation tanks heating.

4.3. Biogas utilizations

In addition to household applications, including cooking and heating, biogas can be used in a wide range, for example, power generation. Furthermore, owing to very high concentrations of methane and carbon dioxide which are harmless to fruits, biogas is widely used as the conditioner for fruits, and vegetables storage and preservation, and seeds deinsectization and storage. Furthermore, through deodorization and purification to remove malodorous compositions and non-flammable gases, biogas is used to produce natural gas (the content of methane is no less than 90%) with higher heating value (5–8% more).

According to the operation of biogas projects in IMAR, biogas is used primarily for household cooking and ranch heating. For cogeneration biogas projects, biogas is used to generate electricity for private uses, mostly. And, in rare cases, generated electricity is uploaded to power grids. Nevertheless, comprehensive utiliza-

Table 4
The development of biogas projects in IMAR.

	Large-sized biogas projects			Medium-sized biogas projects		
	Operation number	Total capacity of biogas pool (10^3 m^3)	Biogas production rate (10^3 m^3/yr)	Operation number	Total capacity of biogas pool (10^3 m^3)	Biogas production rate (10^3 m^3/yr)
2003		0			0	
2004		0		1	0.15	4.50
2005	4	0.70	56.00	1	0.15	4.50
2006	5	3.35	666.00	1	0.15	15.00
2007	8	12.25	4337.00	1	0.15	15.00

tions of biogas slurry and residue have not yet been fully exploited. In several biogas projects, biogas slurry is primarily used as foliar fertilizer for vegetables and top dressing for crops irrigation, and biogas residue is used as basal fertilizer for soil.

5. Case study

5.1. Mengniu Austasia Demonstration Pasture

5.1.1. Description

The Mengniu Austasia Demonstration Pasture, located in Shengle Economic Development Zone of Helingeer County, Huhhot with the area of 8848 acres and capacity of 10,000 cows, was invested by Mengniu Founding Industry Management Co., Ltd., Asia Australia Pty., Ltd., and Salim Group (Indonesia), jointly, at the amount of ¥200 million. In 2006, the Large Scale Biogas Power Generation and Comprehensive Utilizations Project for Mengniu Austasia Demonstration Pasture was invested by Mengniu Biomass Energy Co., Ltd. This project is a demonstration project on large scale biogas power generation technology endorsed by the MOA, China, the United Nations Development Programme (UNDP) and Global Environment Facility (GEF), with the capacity of 1.36 MW, and granted as "The Demonstration Project on Large Scale Biogas Power Generation Technology to Promote the Commercialization of Renewable Energy Capacity-Building Project in China," by UNDP. It is also one of the first batch of agricultural biogas power generation projects approved as the Clean Development Mechanism (CDM) Project by the National Development and Reform Commission (NDRC), China.

The primary function of this project is to solve the ecological and environmental issues caused by excrement from 10,000 cows. Entire process flow is designed to consist of underground pipeline network for excrement transport, urine flushing water collection system, grit removal pretreatment system, biogas fermentation system, biogas purification and storage system, biogas power generation and uploading system, biogas slurry and residue separation system, organic fertilizer production system, and utilizing and heating system for waste heat from cogeneration. It also serves the purposes to promote circular economy by transforming waste into useful resources and to exploit the potential of bioenergy through comprehensive utilizations of biogas. Special features of this project are listed in the followings:

(a) Large scale, high solid content in feeding and effluent, cogeneration, and ecological recycling.
(b) Key technologies and equipment were imported from Germany and other countries.
(c) Equipped with innovative grit removal device.

Detailed technical specifications are listed in Table 5.

5.1.2. Comprehensive utilizations of biogas

In this project, biogas produced is mainly used for power generation, where 90% of the electricity generated is uploaded to power grids and 10% is used at the farm, internally. Waste heat from cogeneration is used as heating at the farm and insulation for anaerobic fermentation to maximize efficiency of bioenergy utilizations. Biogas slurry is used as top dressing for 7000 acres of seedling base and grassland. Biogas residue is mostly used as basal dressing for golf course, vegetable bases and grassland. Some biogas residue is used to manufacture granular fertilizer to be sold as merchandise. This project has fully implemented the objectives of reduction, detoxification, and reclamation of pasture waste.

5.1.3. Economic, social and environmental benefits

Total investment of this project is ¥60 million from Mengniu Biomass Energy Co., Ltd., solely. Currently, the cost of power generation is ¥1.496/kWh, and on-grid price (tax included) is only ¥0.507/kWh. Therefore, this project is in great deficit, as shown in Table 6. However, this project is still undergoing experimental and explorative stage to acquire experience for future development. In 2006, this project successfully applied for the CDM Project, according to the relevant provisions of the Kyoto protocol, and signed a purchase agreement with a Dutch carbon trading company. The CO_2 emission reduction of this project is about 25,000 tons per year with the price of €8.0/tCO_2e. Therefore, economic incomes will be about ¥2 million (€1 ≅ ¥10), every year. But due to the quota is relatively small, there are many difficulties in the transaction process, which has not been completed, so far. In addition, organic fertilizer production has not been commercialized as anticipated by the original design, yet, that has consumed about ¥50 million investment to process 150 tons of biogas residue, every day. At present, biogas residue is piled on the ground and biogas slurry is provided freely to surrounding nursery gardens for about 150,000 acres. Once, the fee is collected after one year, it can also increase economic incomes for this project.

From the aspects of social and environmental benefits, firstly, this project provides a feasible and profitable pattern of operation for other breeding enterprises, which is a pattern of green circular economy for the integration of planting, breeding, production, biogas power generation, and organic fertilizer, based upon the Mengniu Austasia Demonstration Pasture. Also, it provides a good demonstration on exploiting more effective means for pastoral waste disposal and recycling, in IMAR. Secondly, it has fulfilled the objectives of reduction, detoxification, and reclamation for pastoral waste to make important contributions to environmental protection and green ecology. Thirdly, for energy saving and emission reduction, greenhouse gas emission reduction of this project is about 25,000 tCO_2 equivalent every year.

5.1.4. Existing problems

The main problems of this project are summarized as followings:

(a) The effectiveness of degritting system in raw material pretreatment process should be improved to attain better outcomes.
(b) Since biogas slurry collecting pond is built outdoors, biogas slurry is frozen and cannot be utilized, during winter time.

Table 5
Technical specifications of studied cases.

Technical parameters	Mengniu Austasia Demonstration Pasture	Baita Breeding Pig Farm	Erdos Demonstration Park
Fermentation technique	CSTR	USR	USR
Anaerobic Fermentation Tank	$2500\,m^3 \times 4$	$600\,m^3 \times 2$	$500\,m^3 \times 2$ (primary), $800\,m^3 \times 1$ (secondary)
Biogas Storage Tank	$1000\,m^3 \times 1$	$480\,m^3 \times 1$	$1000\,m^3 \times 1$
Fermentation temperature	37 °C	30–35 °C	30 °C
Heating measures	Waste heat from cogeneration	Boiler, solar power, greenhouse, and insulating material	Coal-burning boiler, and biogas boiler
Desulphurization method	Biological desulphurization	Chemical desulphurization	Chemical desulphurization
Desulfurizer		Ø $1.0 \times 1.2\,m \times 4$	Ø $0.80\,m \times 2$
Dehydrator	$10\,m^3 \times 2$	4	Ø $0.25\,m \times 2$
Automatic Control System	Siemens S7-400 Series PLC		
Solid–liquid separator	Slurry separator 3000 W		
Organic fertilizer plant	Palletizing machine (commissioning)		
Biogas slurry and residue collecting pond		$500\,m^3$	
Processing capacity	Cow excrement: 500 tons/day, Sewage: 250 tons/day	Pig excrement: 38 tons/day, Sewage: 30 tons/day	Sheep excrement: 30 tons/day, Sewage: 25 tons/day
Feeding frequency	8 times/day	2 times/day	2 times/day
TS	8–12%		
Biogas production rate	5.11 million m^3/yr	0.4015 million m^3/yr	0.3285 million m^3/yr
Biogas composition	65% of CH_4, hydrogen sulfide 200 ppm		
Installed capacity of power generator	1.36 MW	50 kw	
Operation time of power generator	7300 h/yr	4380–5475 h/yr	
Power generation	5.475–6.57 million kWh/yr	0.1825–0.2190 million kWh/yr	
Power generation efficiency	26.9–32.3%	29.80%	
Waste heat from cogeneration	10,000 kWh/yr		
Organic fertilizer production	30,000 tons/yr (organic matter 50–60%, NPK ≧ 3.5%)[a]		
Production of biogas slurry	144,000 tons/yr		
Reducing greenhouse gases emissions	Equivalent of about 25,000 tCO_2/yr		

[a] National standard: organic matter ≧ 30%, NPK ≧ 4%.

(c) Some equipments (such as generator and fermentation equipment) were imported, which do not conform to domestic conditions to seriously affect the effectiveness.

5.2. Baita Breeding Pig Farm

5.2.1. Description

The Baita Breeding Pig Farm, located at eastern suburb of Huhhot with a floor space of 300 acres, is the demonstration project on modern agriculture appointed by the NDRC as the key breeding pig farm based on the technologies transferred from Inner Mongolia Agricultural University, and the member of the Council of the National Swine Industry Association of China Animal Agriculture Association. In addition, it is the demonstration base of modern agriculture for the integration of production, education and research, and is the largest base of breeding pig and live pig production, in IMAR. Now, it has been appointed as the National Livestock Reserve Base by the Ministry of Commerce, China.

In order to process excrement from 10,000 pigs on-hand, to implement waste reclamation, the Medium Scale Biogas Project for Baita Breeding Pig Farm was established through the financial support from both central and autonomous region governments, and investment from the farm. Entire process flow of this project is designed to consist of raw material pretreatment system, biogas fermentation system, solar energy system, biogas purification system, biogas storage system, power generation system, and biogas slurry and residue storage system. Special features of this project are listed in the followings:

(a) Four different heating measures were applied, such as boiler, solar energy, greenhouse, and insulation to ensure fermentation temperature, and to enhance fermentation efficiency and biogas production rate.
(b) Complete domestic manufactured equipment.
(c) Low personnel cost.

Detailed technical specifications are listed in Table 5.

Table 6
Financial analysis of studied cases.

Item	Mengniu Austasia Demonstration Pasture	Baita Breeding Pig Farm	Erdos Demonstration Park
Total investment	¥60 million	¥4.5 million	¥5.10 million
Equipment investment		¥2.0 million	
Electricity expenses	¥302,400–352,800/yr		
Maintenance	¥180,000/yr		
Water bill		¥217.8/yr	
Fuel cost		¥12,000/yr	
Desulfurizing agent		Free for the first year	
Personnel expenses	¥700,000/yr	¥18,000/yr	¥120,000/yr
Operation cost	¥1.23 million/yr	¥30,000/yr	
Power generation cost	¥1.496/kWh		
On-grid price (tax included)	¥0.507/kWh		
Power output	¥2.775–3.33 million/yr		

5.2.2. Comprehensive utilizations of biogas

In this project, biogas is utilized in several ways, such as power generation, and fuel for boiler and cooking at the farm. In addition, about 2 m^3 of biogas is provided freely to households around the farm, every day. Biogas slurry is processed to produce organic fertilizer. Part of the organic fertilizer is used at the Baita Organic Vegetable Base, where potatoes, blueberries and various kinds of vegetables are planted, and some is provided freely to farmers in the surroundings, for the first year. Biogas residue is processed to produce organic fertilizer to be applied as basal dressing at the Baita Organic Vegetable Base.

5.2.3. Economic, social and environmental benefits

From the aspect of current economic benefit, the electricity generated from biogas is mainly used at the farm internally to save electricity bill for ¥76,650/yr, based upon the local electricity price of ¥0.42/kWh. After deducting the operation cost (including water bill, fuel, and personnel), there will be a surplus for about ¥45,000/yr, as shown in Table 6. Now, biogas slurry is provided to farmers for free. A year later, there will be a charge for biogas slurry, which can increase the incomes of the project. Right now, the profits of this project mainly come from selling organic vegetables (using biogas slurry and residue as organic fertilizer) and pork.

From the perspective of social and environmental benefits, firstly, this project provides a feasible and profitable pattern of operation for other similar breeding enterprises, which is a pattern of green circular economy for the integration of planting, breeding, biomass power generation, and organic fertilizer, based upon Baita Breeding Pig Farm. Also, it provides a good demonstration on exploiting more effective means for pig excrement disposal and recycling, and organic food production, in IMAR. Secondly, it has fulfilled the objectives of reduction, detoxification, and reclamation for pig excrement to make important contributions to environmental protection and green ecology. Thirdly, for energy saving and emission reduction, greenhouse gas emission reduction of this project is about 182 tCO_2 equivalent every year.

5.2.4. The existing problems

This project has only been operating for 9 months at the time of on-site survey. Major problems are summarized in below:

(a) Waste heat from cogeneration has not been recycled, yet.
(b) In winter, the insulation and heating measures are not good enough.
(c) Due to low TS concentration of the raw materials, the effectiveness of fermentation and the biogas production rate are seriously affected.

5.3. Erdos Demonstration Park

5.3.1. Description

The Erdos Demonstration Park of Modern Agriculture and Animal Husbandry Technology, located at Hailesu Village, Bainijing town, Dalate County, with an area of 6030 acres, is constructed by the People's Government of Erdos City, the People's Government of Dalate County, the Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences, the Wantong Road & Bridge Group Co., Ltd., and Valmont Industries, Inc., jointly, with the total investment of nearly ¥140 million. In order to set good patterns for the development of agriculture and animal husbandry in Erdos and IMAR, the main tasks of the Park are to launch scientific researches, to conduct experiment, to promote technology, to enhance technical training, to summarize experience, to develop new products, to cultivate talents, and to create outstanding economical, social, and ecological benefits. According to the overall structure and layout, the Park can be divided into 6 parts: planting area, cultivating area, biogas and compost demonstration area, agriculture area, farming machinery area, and the area for daily life, scientific research, and technical training. Biogas and compost demonstration area is established to deal with excrement and waste from the park and is under test run, for now. Special features of this project are listed in the followings:

(a) Adopting two fermentation processes (primary and secondary) to improve the utilizations of raw materials and increase biogas production rate.
(b) Mostly imported equipment.
(c) Biogas residue is used as the raw material for composting to produce organic fertilizer through biology fungus fermentation.
(d) Utilizing biogas slurry as culture solution for chlorella production.

Detailed technical specifications are listed in Table 5.

5.3.2. Comprehensive utilizations of biogas

Biogas is mainly used for heating and cooking, internally. After advanced treatment, biogas slurry is used to produce organic fertilizer, which is transported to agriculture area for planting vegetables and melons, and cultivating small chlorella. Chlorella is then used to feed sheep. Biogas residue is used as the raw material for composting to produce organic fertilizer through biology fungus fermentation and mechanical agitation. These organic fertilizer are used in planting area and agriculture area for corns and high-quality purple pasturage clover planting.

5.3.3. Economic, social and environmental benefits

This project is still under test run and the economic benefits analysis of biogas operation cannot be carried out completely. However, due to some equipment and technical cooperation and services are provided freely by Valmont Industries Inc., the total investment has been greatly reduced. The water comes from the well dug by this project to save the water bill. Biogas is used for heating and cooking in the park. Biogas slurry is mainly used for vegetable field irrigation and chlorella production. Through biology fungus fermentation and mechanical agitation, biogas residue is used for composting to produce organic fertilizer, which is then used at planting area and agriculture area. This project has fully implemented comprehensive utilizations of biogas, biogas slurry, and biogas residue to save the costs of fuel, chemical fertilizer and pesticides to generate remarkable economic benefit, as well as social and environmental benefits.

5.3.4. The existing problems

Though, this project is still under test run, the problems are summarized as followings:

(a) This is no effective measures of insulation for raw material regulation pond to seriously affect fermentation efficiency.
(b) In winter, boilers (both coal-burning and biogas-burning) are used for heating and insulation for fermentation tank to increase the fuel cost and to cause environmental problems.

6. Results

In China, comprehensive utilizations of biogas have formed a complete cycle to fulfill the requirement of circular economy. While treating industrial and agricultural waste, produced biogas can be used for household cooking, heating and warming, food and fruit preservation, power generation, and natural gas. Biogas slurry and residue are mainly used in four areas: (i) fertilizer: organic basal and top dressing, foliar liquid fertilizer, soil improvement;

(ii) feeding: raising pig, fish and earthworms; (iii) biopesticide: the prevention and control of diseases and pests, and seeds soaking; (iv) culture solution: edible mushroom cultivation, soilless cultivation, seedlings nurturing; and (v) natural gas: after deodorization and purification, biogas is used to produce natural gas.

The development and biogas utilizations projects have not only solved the problems of environmental and ecological issues caused by excrement, reduced greenhouse gases emissions, but also developed a new pattern of energy consumption to effectively integrate environment protection with ecological protection, and created conditions to fundamentally solve the problem of energy, resources and environment.

6.1. Economic benefits

Economic benefits of biogas project can be summarized as followings:

(a) To reduce the pollutants emission fees.
(b) To reduce fuel cost, save the expense of fertilizer and pesticide and create incomes by selling organic fertilizer made from biogas slurry and residue. Based on the statistics from the Agricultural and Environmental Protection Energy Supervision Stations in Bayannaoer, using biogas for cooking and heating has saved the cost of coal for ¥1080 (3 tons) per household. Using biogas slurry and residue as a fertilizer for planting early ripening muskmelon in greenhouse, the production has been increased by 350 kg/acre, the quality efficiency has been enhanced by ¥1.0/kg, and the production profits has been increased by ¥3850/yr; the cost of chemical fertilizer (diammonium, urea) has been reduced by ¥240 (100 kg); and the cost of pesticide has been reduced by about ¥100. In addition, using fodder made from biogas slurry and residue to feed pigs, the offtake pigs has been increased by 6 to increase the incomes for ¥720. Also, according to the MOA, the investment in village biogas projects is around ¥3.0 billion, which can save direct spending on fuel and chemical fertilizer for about ¥1.15 billion, in 2009.
(c) To reduce utility bill and create incomes by uploading generated electricity to power grids. Based upon statistics, the value of 1 m^3 biogas shall be ¥0.99, by generating electricity 1.8 kWh at a rate of ¥0.55/kWh [15].
(d) To create job opportunities and increase farmer's incomes. According to the MOA, ¥3.0 billion additional investment in village biogas projects will increase more than 100,000 jobs for mechanics so to increase the incomes of farmers as the constructing mechanics for about ¥1.2 billion.
(e) To create incomes through CDM, due to emission reduction of greenhouse gases, such as CO_2 and CH_4. It was estimated that in 2005, in China, large and medium scale biogas projects reduced emissions of CO_2 (from 0.54 to 1.51 million tons/yr) and CH_4 (from 0.025 to 0.072 million tons CO_2e/yr) [16] to acquire economic benefits of ¥116–269 million, according to international market price.

6.2. Social benefits

Social benefits of biogas project can be summarized as followings:

(a) To reduce the labor intensity of farmers and herders by changing the structure of energy consumption. Biogas is an alternative energy source to replace traditional energy consumption, such as wood, coal, straw and liquefied petroleum gas (LPG). As a convenient, clean and healthy energy source, biogas is used for cooking and heating to reduce the intensity of domestic work for women. Consequently, it will save time in accessing and using firewood, straw and coal for cooking and other housework to increase time for production work, leisure, entertainment and rest, and to reduce negative impact on women's health from traditional energy use.
(b) To significantly change production pattern and lifestyle and increase the life quality for farmers and herders. Through biogas engineering, bioenergy can be effectively utilized (including power generation, heating, lighting and cooking) and biogas slurry and residue can be used to manufacture organic fertilizer for agricultural production (to save the inputs for production and increase productivity). Therefore, through increasing incomes and decreasing expenditure, the quality of life for farmers and herders is certainly improved with higher incomes.
(c) To stimulate domestic demand, provide employment opportunities and increase incomes. According to statistics from the Rural Area Eco-Energy Station of IMAR, by the end of 2008, the State has granted ¥135 million for the construction of biogas projects in IMAR, along with funding support of ¥20 million from the Bureau of Husbandry and the Development and Reform Commission of IMAR, which has increased the production and sales of cement, brick, gravel, steel and other building materials, for example, 60,400 tons of cement, 71,726 thousand pieces of brick, 56,100 m^3 of gravel and 227 tons of steel were needed for these new biogas projects to cost ¥46.949 million. In addition, more than 1500 jobs were created through these biogas projects to increase the incomes of skilled construction workers for about ¥28.202 million. Furthermore, the investment in village biogas projects in 2009 has resulted in the increase of sales volume of building materials, such as cement (6.5 million tons), bricks, steel (0.5 million tons), and agricultural vehicles (17 thousand) for feeding and discharging. More than 2 million households will be directly benefited from these investment by saving fuel, chemical fertilizer and increasing more than 0.1 million jobs as construction workers and mechanics.

6.3. Environmental benefits

Environmental benefits of biogas project can be summarized as followings:

(a) To reduce greenhouse gases, such as CO_2 and CH_4, emissions. According to statistics from the Rural Area Eco-Energy Station of IMAR, by the end of 2008, biogas is used at 260,000 households to save nearly 200,000 tons of standard coal, and to reduce CO_2 emissions for 500,000 tons, annually. Also, according to the MOA, by 2008 in China, there are 30.5 million households to use biogas. Biogas projects for farms can produce 12.2 billion m^3 of biogas, which is equal to 18.5 million tons of standard coal (equivalent to the annual storage of 0.11 billion acres of forestland) and the emission reduction of CO_2 is more than 45.0 million tons. In addition, there will be 0.385 billion tons of organic fertilizer manufactured from biogas slurry and residue.
(b) To improve the environmental sanitation of agricultural and pastoral areas and fulfill resources recycling. Biogas projects have promoted rational utilizations of various waste from rural and pastoral areas in IMAR by converting waste into the clean, green bioenergy and efficient organic fertilizer to effectively alleviate the situation of energy scarcity, to significantly improve the sanitation conditions, and to successfully prevent the common diseases in rural and pastoral areas. In addition to resolving environmental and ecological issues and resources reclamation, in villages, biogas engineering turns waste into wealth.

(c) To extensively enhance organic matter content of cultivated land and greatly relieve the pollution resulted from pesticide and chemical fertilizers. Biogas fermented substance is rich in humus which can facilitate soil aggregation, and improve physicochemical properties and mellowness of soil. The widespread use of fermented substance will reduce the use of pesticide and fertilizers and effectively keep soil from packing together, and make a positive contribution in improving the ecology and environment of animal husbandry.

(d) To improve the ecology and environment of grassland. Vast grassland is the important material basis for the development of animal husbandry, and the production and livelihood of herders in IMAR, and is also an ethnic enclave. Animal husbandry, as the main economic source, has created a unique advantage and basic industry in IMAR. Therefore, it is very important to carefully deal with the relationship between the ecological and environmental protection of grassland and the development of economic construction. In order to integrate economic construction and ecological and environmental protection with increasing herders' incomes and pastoral society development, careful consideration from the aspects of production and livelihood of herders shall be the foundation of the development of biogas projects in IMAR. Furthermore, in order to promote economic sustainable development for pastoral areas, it is important to fundamentally change the traditional production, lifestyle and concepts of herders, to rationally utilize energy resources, and to transform the operation and management of animal husbandry.

(e) To ensure the quality of pastoral products. Using biogas effectively can lead to the innocuous treatment for excrement and significant enhancement on environmental sanitary conditions so that the hygiene of aquaculture production can be guarantee and the quality of meat, eggs and other products can be improved.

6.4. Existing problems

Though with strong support from central and local governments, there are several prominent problems of the development of biogas projects in IMAR, such as: poor quality, low utilizations rate, inadequate equipment and outdated operation and management, chaotic market of biogas products, high potential hazard, technical problems for electricity uploading and incompetent policies and insufficient financial support.

(a) Poor quality: More hasty, less speed. Since late start for the development of modern biogas technology in China, in order to catch up with developed countries, quantity was initially emphasized. The quality of construction was somehow misplaced. For some local biogas projects, the only concerns were the completion of construction work and scheduling of project implementation. In order to save cost and trouble, quality of building materials and construction team were often neglected. Therefore, the quality of entire project was poor. As the consequence, most of the systems were completely or partially out of services, extremely difficult to be reconstructed or repaired and could not be operated normally.

(b) Low utilizations rate: Though the development of biogas projects for households has made great achievements in China, lately, there is no unified technical guidance, promulgated by authorized industry association, for large and medium scale biogas projects. Due to vast regional difference between southern and northern China, many different fermentation techniques were applied to various biogas projects without rational design, skillful construction and adequate, compatible technology.

In general, the initial purpose of biogas projects was mainly for waste disposal and bioenergy production. Therefore, other resources utilizations, such as organic fertilizer production and waste heat recovery from biogas cogeneration, were not carefully considered during project design. Majority of the established biogas projects did not implement biogas cogeneration. Hence, during winter time, for projects adopting normal temperature fermentation or using external heating for medium temperature fermentation, biogas production rate cannot be stable, which has seriously affected the effectiveness of operation and greatly reduced net energy output. In addition, biogas slurry and residue are not utilized effectively. Although, there are post-processing device for biogas slurry and residue in some biogas projects, rational utilizations of biogas slurry and residue cannot be achieved due to lacks of experience. Besides, the commercialization of organic fertilizer market has not been formed. Thus, the device has not been able to play their roles and the economic value of biogas slurry and residue cannot be revealed.

(c) Inadequate equipment and outdated operation and management: Due to particular weather condition in IMAR, special heating and insulation system is required for biogas projects to maintain a stable and effective biogas production rate. Even though, biogas cogeneration was applied in some projects, waste heat from cogeneration was not fully recovered and utilized. Therefore, heating and insulation system for biogas projects are ineffective and biogas production rate is low.

Owing to special characteristics of each process of biogas engineering, such as raw material handling and fermentation, anaerobic digestion, utilizations of biogas, there are still some problems of processing and manufacturing techniques for many apparatus (i.e. degritting, feeding pump, anaerobic digestion device, materials mixing, solid–liquid separation, the biogas storage equipment, biogas cogeneration equipment, etc.), such as, specificity, compatibility, manufacturing process, and materials. Overall, the problems are high energy consumption, low efficiency, high frequency of malfunction, poor compatibility and supporting, unable to operate stably year-round, difficult to be adapted for different raw materials, different application requirements in fermentation process, and no standardized anaerobic digestion equipment.

With increasing amount of biogas projects, there is a need for more effective and sufficient operation, management and technical service system. Normally, staff of the biogas projects (fulltime or temporary) do not have thorough understanding of relevant technologies and standards on biogas engineering. Therefore, there is no stability or long-term goal for the management of biogas project. In addition, due to lacks of technical training, many farmers and herders are unfamiliar with the technologies of scientific management and comprehensive utilizations, and unable to operate and manage the system. Furthermore, there are no prompt and effective follow-up service for biogas projects, since there are no complete after-service management teams, and systematic and comprehensive guidance and training. A considerable number of biogas projects cannot be operated effectively, and even some parts of the system cannot be operated normally, which have resulted in less enthusiasm and inactiveness of aquaculture enterprises, farmers and herders to post severe obstacle to the development of biogas projects in IMAR.

Chaotic market of biogas products: Currently, the market of merchandized biogas products is confused and full of disordered competition and products with uneven qualities. Many unqualified, inferior and rough biogas products without three labels (production date, quality certificates, and manufacturer)

are illegally circulating in the market to totally break the operation mechanisms of the system.

High potential hazard: According to the survey, among the management staff of large and medium scale biogas projects, only 30% is full-time and 70% is part-time. They do not have sufficient safety awareness and technical training to eliminate potential hazards, including electric leakage, biogas leakage, poisoning, and drowning. Also, there is no effective internal safe production responsibility system to safeguard the operation. Moreover, in order to save cost, many necessary expense were cutback to cause the increase of insecure and unstable factors.

Technical problems for electricity uploading: For small scale biogas power generation, electricity generated cannot be uploaded to power grids. (So far, there is no policy to support small scale biogas power generation to upload electricity to power grids.) Since the power demand for household is intermittent, there is no need to generate electricity in full load. Hence, economic benefits from power generation cannot be fully implemented. Only 1% of the biogas projects adopt biogas power generation, where uploading to power grids is rare. Mainly, biogas is only used for burning, as an alternative energy source to coal, which has greatly reduced the economic value of biogas and affected its energy conversion efficiency.

Inadequate policy and insufficient financial support: In China, the capital of investment in biogas projects are mainly from discount loans supported by the State and self-financing by construction units. Without appropriate incentives and restrictive policies, it is difficult to mobilize and attract investment effectively, which is an important factor to affect the technical development of biogas project.

7. Conclusions

Currently, most of these biogas projects in IMAR are invested by farming enterprises with governmental funding support. After the completion, farming enterprises have the ownership of the projects and are responsible for the operation and management. This kind of cooperative mode between farming enterprises and government does not possess high risk for large farming enterprises. But for medium and small farming enterprises, due to high investment on biogas projects, low profits and slow return of investment for farming enterprises, it will be burdens for enterprises in trying to maintain farming and biogas productions, simultaneously. In order to promote the development of biogas projects in IMAR, some advices are recommended, based upon the results of this study.

7.1. To institute biogas projects development plan

With huge biogas production potential in IMAR, it is recommended that the IMAR government should propose the short-, mid- and long-term development objectives, keys of development, implementing proposal and guarantee measures, in accordance with the current status of resources and livestock husbandry development plans. With a clear developing goal, capital, technology and management measures can be actively implemented to promote the achievement of planning objectives, which possesses very significant instructive meaning to both government and the enterprise. In addition, counties and cities should be encouraged to establish a special plan in accordance with their own resources status and the market of biogas comprehensive utilizations.

7.2. To improve engineering standards

According to the climate characteristics in IMAR, exclusive technical specifications for engineering & scientific research should be compiled to provide the uniform technical standards for project design and convenient conditions for project organization and implementation. In order to match with project scale and engineering mode, farming scale of the enterprise is also strictly regulated. Furthermore, more detailed information regarding bidding proposal (including technical bid and business bid) shall be included, as well as required documentation for the confirmation of the legal status of bidder (such as business license, tax registration certificate, ISO 9000 certificate, safety production certificate, and financial reports for the last three years).

7.3. To improve incentive policies

Governmental supporting policies, such as financial support, subsidy mechanisms for biogas electricity price, economic incentives for the utilizations of biogas slurry and residue, and explicit standards for biogas slurry and residue applications, are the important driving forces to promote the development of biogas industry. For those biogas power generation companies cannot make profits for fixed price policy, it will help to improve the financial situation of the enterprise to attract more investors and businessmen to enter this field and to promote the healthy development of biogas industry, with appropriate financial subsidies provided by government.

7.4. To strengthen R&D for engineering, technology and equipment

In order to achieve professional and scale-up production, it is essential to learn the appropriate situation of biogas engineering for China, particularly, specific equipment and manufacturing technology for IMAR, and to explore mass production technology for all kinds of equipment for biogas engineering, as well as engineering assembling technology. It is also recommended to set up special funds to support scientific research institutes and enterprises for their R&D work on integrated innovation of special equipment related to biogas power generation engineering and technology revolution, for example, (i) highly efficient equipment for excrement pretreatment; (ii) highly efficient degritting equipment for excrement; (iii) feeding equipment suitable for high solid material; (iv) integrated anaerobic digestion device for biogas production and storage; (v) heating and thermal insulation techniques, and materials selection for anaerobic tank walls; (vi) submersible mixing equipment with high efficiency, slow rotary speed and low power consumption; (vii) highly efficient biogas power generators with waste heat recovery equipments; (viii) storage system with insulation facilities (to prevent freezing in winter) for biogas slurry and residue; (ix) durable solid–liquid separation equipment; and (x) standardized, serialized and industrial production technology of anaerobic digestion equipment.

7.5. To study the models of comprehensive utilizations of biogas through demonstration projects

In order to promote the development of biogas projects in IMAR, it is necessary to construct several biogas projects, invested by government and enterprises, jointly, to demonstrate different modes of biogas comprehensive utilizations in IMAR. Application modes of demonstration projects, such as biogas cogeneration, biogas purification, etc., should be selected carefully and rationally, according to local climate characteristics and energy demands, as well as the utilizations of biogas slurry and residue. Therefore, a viable economic mode of biogascomprehensive utilizations

should be established to acquire practical experience through operation.

7.6. To refine the management system

With clearly defined responsibility, it is recommended for IMAR government and competent authority of biogas projects to establish an effective management system, through the work assignment liability system and an effective work platform, to perform refined management for investment capital, construction projects, and related information of biogas projects. (i) Capital management. It is important to strengthen the capital management of a project by utilizing centralized planning, management and resource allocation on funds to accomplish the maximum effects. In addition, surveillance system should be established to monitor the use of funds, and to enhance the auditing and supervision on capital and material of the projects during the construction, through local auditing departments, to prevent any diverted uses or misuses. (ii) Project management. It is necessary to implement basic management procedures for construction projects, in accordance with planning, management, design and construction. In addition, it is also required to establish internal monitoring, follow-up monitoring, engineering supervision, project implementation evaluation and auditing system for each project to ensure the engineering quality. (iii) Information management. It is essential to update all information regarding the number, the scale, and the effectiveness of biogas projects, in time, for statistical analysis, in order to have fully understanding of progress status of projects. Furthermore, it is required to establish construction projects reservation database, at district and town levels, to lay the foundation of continuous development of biogas projects in IMAR.

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